Fabrication and characterization of uniform 2D plastic microlensarrays by Deep Lithography with Protons

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The efficient integration of arrays of opto-electronic devices into photonic data handling systems calls for the development of high-quality, uniform microlensarrays. In this paper we present our latest results on the fabrication of plastic microlenslet arrays using Deep Lithography with Protons (DLP). We highlight the geometrical dimensions, the shape and the uniformity of our microlensarrays measured in reflection mode with an optical non-contact profiler. Next we present the optical performances of the microlenses. A Mach-Zehnder interferometer was used here to measure the focal length, the aberrations and the deviation from sphericity of the microlenses.

1. Introduction

Microlensarrays are assuming growing importance owing to the increasing miniaturization of electrical and optical components. Lens arrays made of glass have been studied for a relatively long time compared to those made of other materials and over the years various fabrication techniques have been proposed: photothermal expansion [1], ion exchange [2] and CO_2 laser irradiation [3]. More recently, extensive studies on fabrication techniques of micro-optical components in new lightweight optical materials have been the research topic of interest of many different research groups. In particular, polymer materials have attracted special attention because of the controllability of their mechanical and optical properties. Many researchers have reported on fabrication methods of microlenses and lensarrays with this material. These methods include photoresist reflow [4], laser beam shaping of photoresist [5], laser ablation [6], photopolymerized [7] and ink-jet printed microlenses [8]. Most of these methods can satisfy the uniformity requirements but are less suitable for rapid prototyping of lensarrays. In this paper we present a technology, named DLP with which we can rapidly prototype arrays of refractive microlenses and which can feature different diameters and pitches and a wide range of numerical apertures. This DLP process consists of a proton irradiation of a PMMA-layer in well-defined regions, followed by a volume expansion of these bombarded zones caused by a diffusion of an organic monomer vapor. The uniqueness of this approach lies in the fact that this particular fabrication process of microlenses is fully compatible with the other process steps of the DLP technology [9] and therefore allows the monolithic integration of these microlenses with other plastic micro-optical components to form replicable and low-cost high precision micro-optical modules.

2. Calibration and Optical Characterization of Microlenses

When the PMMA sample is irradiated with 8.3-MeV protons according to a certain lensarray design, the sample is placed in a temperature-controlled reactor. If the desired temperature is reached, the MMA monomer is injected with a syringe while a pressure probe is used to detect a possible leakage of the reactor. Diffusion then takes place during a certain well-controlled time period. Finally the microlenses are stabilized by reducing the temperature and sustaining it for several hours. For calibration purposes we have irradiated a sample in such a way that 10 columns of 10 microlenses were created. Each column should consist of 10 identical microlenses created with the same proton charge. For increasing column number the proton doses ranged from 0.1 nC to 1 nC in steps of 0.1 nC. After irradiation of this 10x10 array of 200 µm cylinders, the sample was placed in a temperature-controlled reactor at 90 °C. Next MMA was injected with a syringe. Diffusion then took place during 50 minutes. Finally the 200 µm microlenses were stabilized by reducing the temperature to 70 °C and sustaining it for 4 hours. A good knowledge of the actual lensprofile is required for the optimization of the fabrication procedure. Various optical and mechanical methods are available to characterize the physical and optical properties such as the surface profile, the surface roughness, wave aberrations, the uniformity of the focal length, the absorption of the material and the refractive index. We will therefore now focus our attention to some of the characteristics of this microlensarray, as obtained by interferometric measurements.

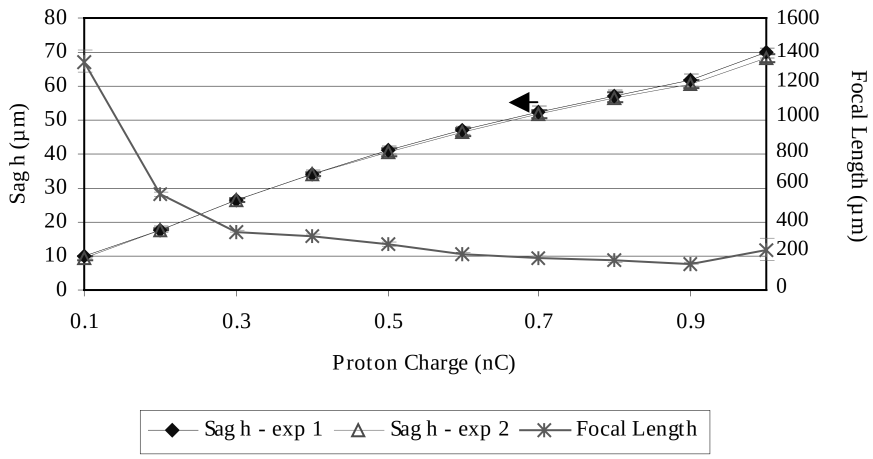

Figure 1: Sag (µm) and Focal Length (µm) as a function of the Proton Charge (nC)

The geometrical dimensions and the sag of the microlenses were measured in reflection mode with a vertical scanning non-contact optical profiler. All lenses in the above studied 10x10 array have a diameter of 200 ± 2 µm, a pitch of 250 ± 4 µm and a RMS roughness on top of the lens of $\lambda/30$ @ 632 nm. Their sags range from 9.77 to 69.73 µm as plotted in Figure . To investigate the reproducibility of these results we have repeated the experiment using the same irradiation and diffusion parameters. From Figure 1 we can conclude that both experiments (exp 1 & 2) give the same results within the error margin of the instrumentation. The studied 10x10 lenslet arrays have a lens density D_n of 16.66 mm^{-2} and a fill factor η of 52.3%.

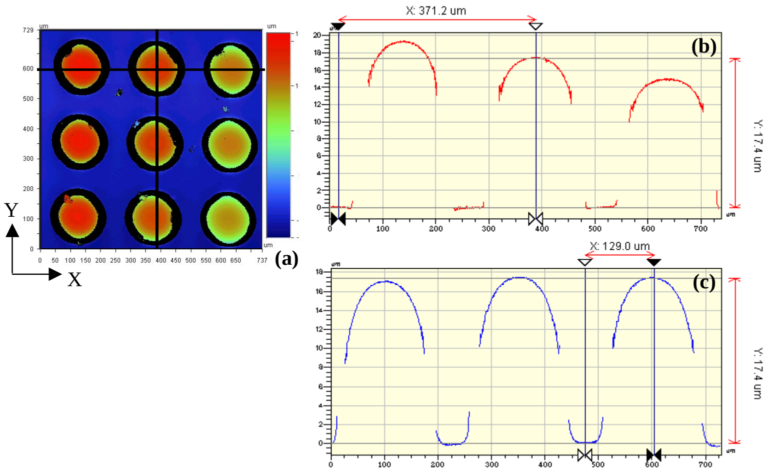

Figure 2: (a) 3x3 array with columns of uniform 200µm microlenses measured with a non-contact optical profiler (WYKO NT2000); (b-c) X- and Y 2D-plot of the microlensarray respectively

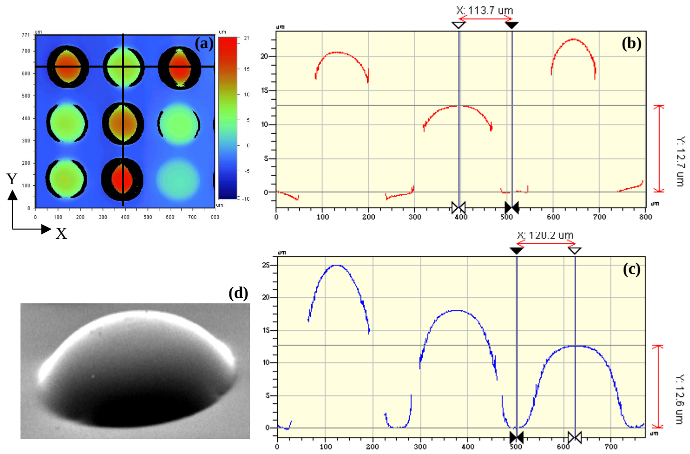

Figure 3: (a) 3x3 microlensarray with variable sag, constant diameter (2a=200 µm) and pitch (P=250 µm) measured with a non-contact optical profiler (WYKO NT2000); (b-c) X- and Y-2D-plot of the microlensarray respectively; (d) SEM picture of one of the microlenses

Once the swelling process calibrated and the repeatability of the process demonstrated, we started exploring the flexibility of DLP for the fabrication of microlensarrays. As a first sample, see Figure 2a, we irradiated a 3x3 array of microlenses such that during irradiation each column received a different proton charge. Next we studied the uniformity of each column of the microlensarray and obtained for each column a deviation on the lens sag of less than 0.5%. In a next step we irradiated a similar 3x3 array but with different proton charges. This results in an array of lenses with variable sag (Figure 3). The fill factor could here be enhanced by using a hexagonal packed array or by decreasing the lens pitch while retaining the diameter at 200 µm. In the near future we would like to go one step further and fabricate microlensarrays with variable diameters, pitches and sags.

To investigate the optical properties of individual lenses one of the most accurate and reliable techniques is interferometry. Particularly appropriate to measure the wavefront aberrations is the Mach-Zehnder interferometer, which has been widely used for microlens characterization shows a Mach-Zehnder transmission interferometer developed for microlens testing. We have used the latter instrument to measure the wavefront aberrations of the microlenses (Figure 4). The other optical performances will be highlighted at the conference.

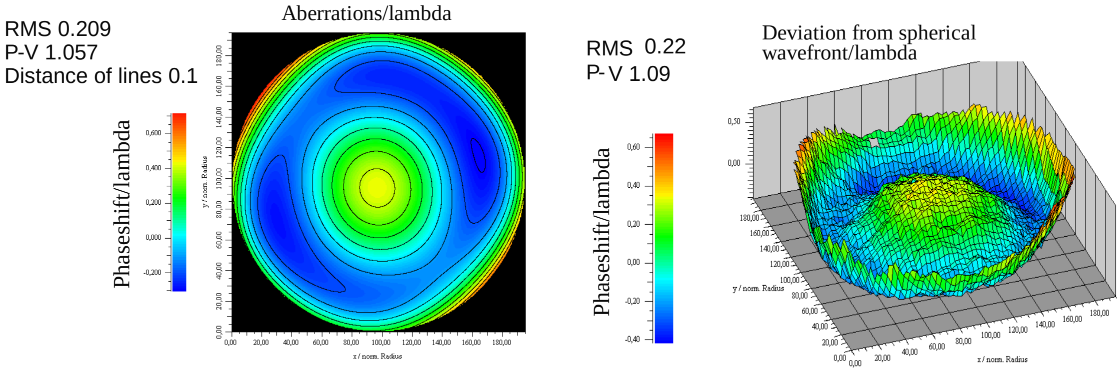

Figure 4: (a) Aberration/lambda for a 200 µm lens with a height of 23 µm; (b) Deviation from a spherical wavefront (lambda) for the same microlens

3. Conclusion

In this paper we have described Deep Lithography with Protons as a fabrication method for spherical microlenses. We reported on geometrical and optical characteristics of different microlensarrays. The geometrical dimensions, the shape and the uniformity of these optical components were measured with a non-contact optical profiler. A Mach-Zehnder transmission interferometer was used to measure the spherical aberrations of the lenses. Furthermore we have studied both uniform microlensarrays and arrays with varying pitches and sags.

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